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THE AERODYNAMICS RANGE: A NATIONAL HISTORIC MECHANICAL ENGINEERING LANDMARK

Edward M. Schmidt

May 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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On the evening of 21 October 1982, the American Society of Mechanical Engineers (ASME) designated the Aerodynamics Range at the Ballistic Research Laboratory as a National Historic Mechanical Engineering Landmark. The award recognizes the facility as the world's first large-scale, fully instrumented ballistic range capable of producing data on the aerodynamic characteristics of missiles in free flight. This publication describes the Range and examines the associated contributions made to technology.

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I. INTRODUCTION

On the evening of 21 October 1982, the American Society of Mechanical Engineers (ASME) designated the Aerodynamics Range at the Ballistic Research Laboratory as a National Historic Mechanical Engineering Landmark. The award recognizes the facility as the world's first large-scale, fully instrumented ballistic range capable of producing data on the aerodynamic characteristics of missiles in free flight.

At the dedication ceremony, Mr. George Kotnick, Governor of the ASME, presented a memorial plaque to Dr. R. J. Eichelberger, Director of BRL. In addition, Mrs. Constance Beims, representing the Honorable Harry Hughes, delivered a citation from the Governor of the State of Maryland in honor of the occasion. The keynote speech was delivered by Dr. Alexander C. Charters, the individual most responsible for the design, construction, and operation of the original Aerodynamics Range. This special publication discusses the nature of the award and of the range. Dr. Charter's keynote address is presented as a fitting finale.

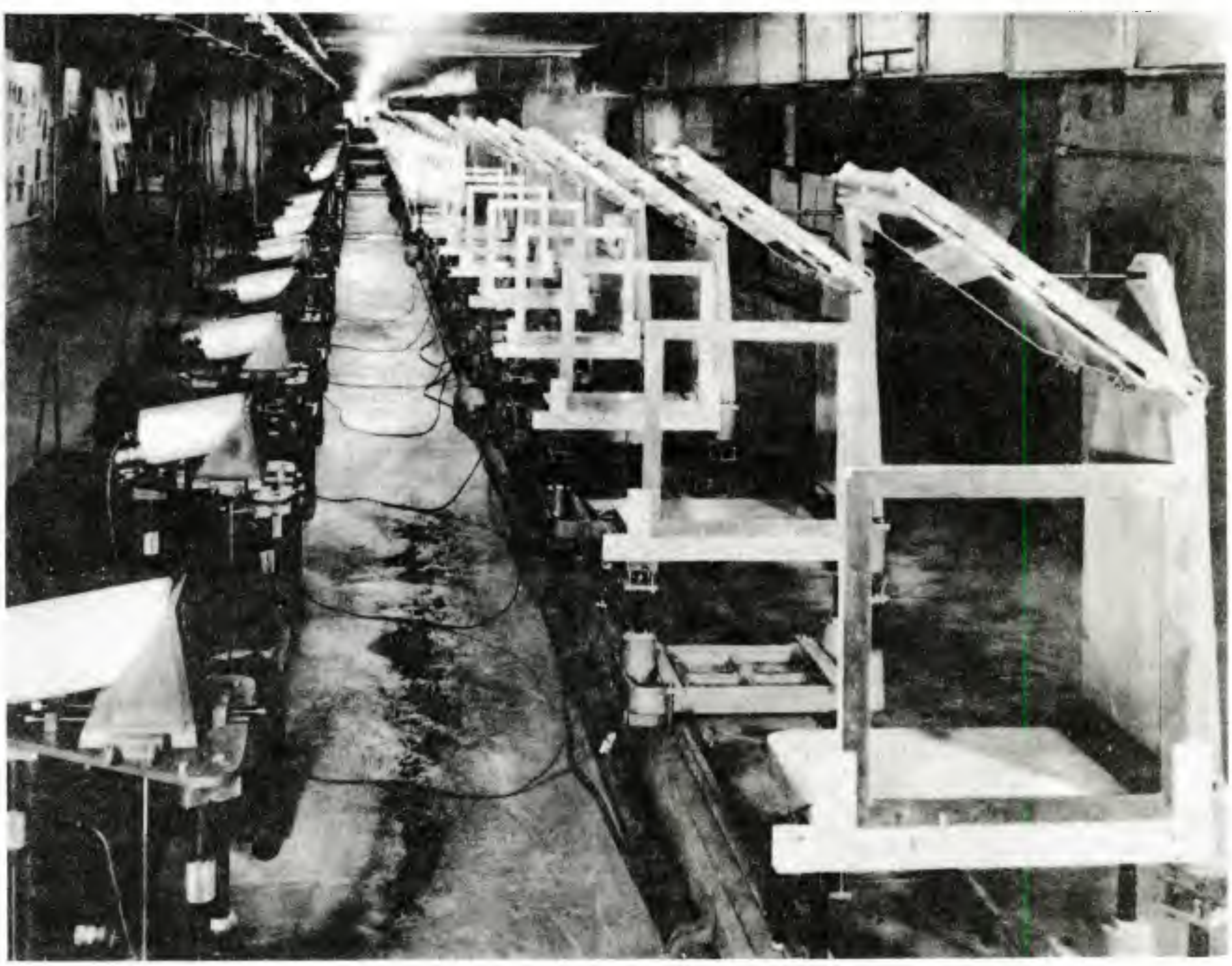


Figure 1. Photograph of the Aerodynamics Range

Figure 2. Mr. George Kotnick, Governor of the ASME, presents a commemorative plaque to Dr. Robert J. Eichelberger, Director of BRL

Figure 3. The commemorative plaque

II. ASME's HISTORY AND HERITAGE PROGRAM

ASME's History and Heritage Landmark Program began in September 1971. To achieve the goals of the program, ASME formed a History and Heritage Committee, composed of mechanical engineers, historians of technology, and a curator of mechanical engineering from the Smithsonian Institution who serves in an ex-officio capacity. All are leaders in their particular fields, and possess a keen interest in our nation's legacy of technological development. The committee provides a public service by examining, noting, recording and acknowledging mechanical engineering achievements that were significant in their day, such as the machinery of a pumping station, a mine engine of almost unheard-of capacity, or the monstrous rocket that carried man to the moon.

The program illuminates our technological heritage, encourages the preservation of the physical remains of historically important works, provides an annotated roster of landmarks, and calls attention to our industrial past.

Landmark mechanical engineering accomplishments fall into three categories: state, national, and international. International landmarks represent a technology that has had a broad influence geographically. Such artifacts may lie in any country, representing either American contributions that have influenced foreign technology, or vice versa. National landmarks represent an advance within their field of technology that is significant to the United States as a whole. State landmarks are of significance to a particular geographical area.

Mechanical engineering landmarks possess some unique feature: the first ever, the oldest extant, the last surviving example of a once widely used type or some other important distinction. The BRL Aerodynamics Range exemplifies the features looked for by the Landmark Program. In the following section, a history of the range and its associated contributions to technology are presented.

III. BRL AERODYNAMICS RANGE

In 1742, Benjamin Robins used a ballistic pendulum to measure the muzzle velocity of a projectile fired from a cannon. The velocities he recorded were much higher than the values predicted by existing theory. This theory assumed the round was flying through a vacuum; therefore, only a modest muzzle velocity was needed to explain the ranges typical of early artillery. Robins' experiment presented the theorist with a contrary fact and led to the identification of aerodynamic resistance (drag) as a force to be reckoned with. It also confirmed the need for valid measurements to accompany analytic developments.

By the early part of the twentieth century, theoreticians working in the area of ballistics were again ahead of their experimentally inclined cousins. Designers had replaced the spherical cannon ball with streamlined shapes typical of modern shell. While such profiles reduced aerodynamic drag, they also tended to be unstable and required spin, obtained from rifled gun tubes, to provide gyroscopic stability. If not given sufficient spin, the projectile would tumble in flight, leading to a drastic increase in drag. While theory could predict performance, measurements were not providing useful comparisons.

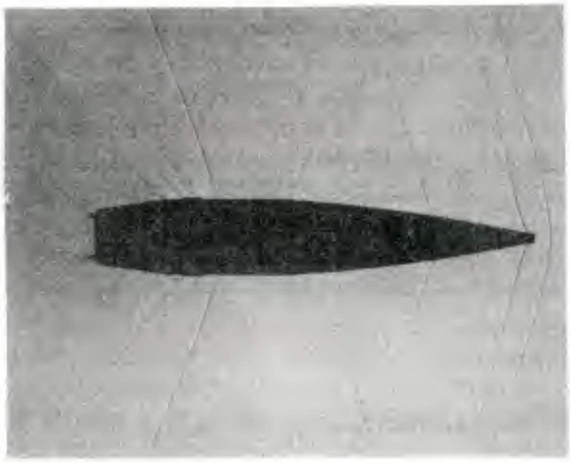
Flight velocities were being measured by firing a magnetized projectile through solenoid coils placed at predetermined intervals along the trajectory and recording on a drum chronograph the time interval between the electric pulses generated by the missile passing through the coils. The angular motion of the projectile, which gives a strong indication of flight stability, was measured by firing through an array of cardboard sheets placed at intervals along the trajectory. The dimensions and orientation of the "key hole" that the missile punched in the sheets described its attitude. This technique created problems since it interfered with the flight of the round and was not sufficiently precise to provide the information required by modern theorists.

To improve the quality of ballistic data, advanced diagnostic techniques were examined by COL H. H. Zornig and R. H. Kent at the Aberdeen Proving Ground. Working under their general supervision, Dr. Charters developed the technology that laid the groundwork for the design of the Aerodynamics Range. This facility was constructed in time to perform invaluable service during World War II. Fundamental contributions were made to the science of ballistics in the areas of data acquisition and analysis, the theory of projectile flight, and the exploration of supersonic aerodynamics. Parallel efforts in the development of tactical and strategic weapons design data contributed to the national defense.

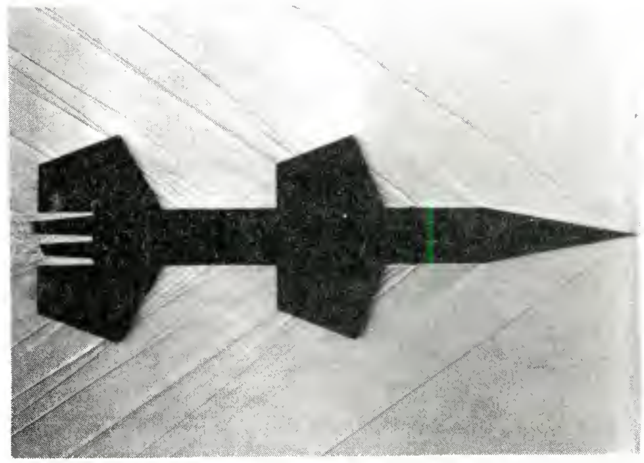
A. Spark Shadowgraphy

Accurate observation of fast-moving objects is essential to progress in many fields of science and technology. One method of freezing motion is flash photograghy, using a short-duration light source. One of the shortest duration sources available is the spark discharge. The first spark photograph was made in 1851, when an unblurred picture of a newspaper clipping attached to a revolving drum was obtained by use of a spark from a Leyden jar, an early form of electrical capacitor. The first spark photographs of projectiles in flight were taken by Ernst Mach in 1888, using a spark discharge triggered by the muzzle blast from the gun. While significant advances were made since the early experiments of Mach, a suitable trigger device for capturing the projectile in the optical field of view remained an obstacle to be overcome before spark photography could be used to record the flight of a projectile through a ballistics range.

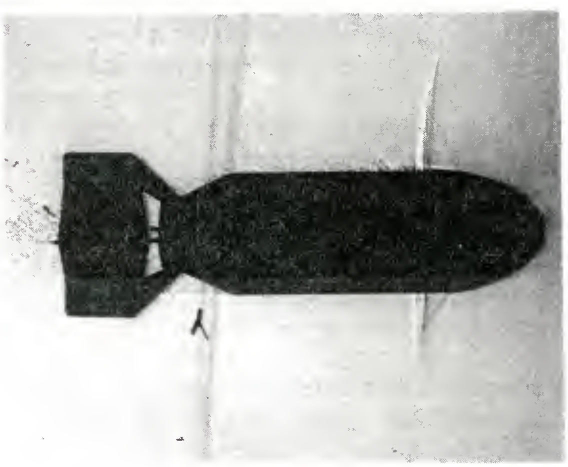
There were five basic requirements for the BRL's ballistic spark photography range: a light source one-millionth of a second in duration and of sufficient intensity to expose a photographic plate, interference - free synchronization of the light source triggering with the passage of the projectile, an array of photographic stations along the trajectory in sufficient density to provide useful data, a survey technique for measuring the distance of stations along the trajectory to an accuracy of .001 foot or



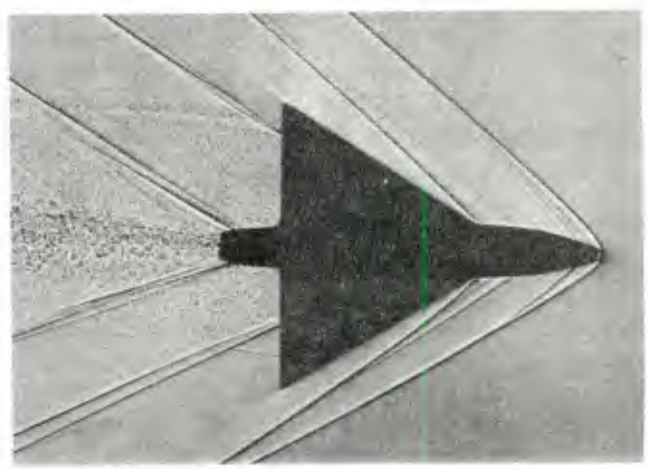
a. Spin-stabilized projectile



b. Missile



c. Bomb



d. Airplane

Figure 4. Typical spark shadowgraphs

better, and a chronograph recording the times of spark discharge to an accuracy of one microsecond or better.

The triggering problem was solved by a chance discovery. During the firing of a machine gun, it was found that the projectile carried an electrostatic charge. This could be used to induce a charge on an antenna placed near the trajectory. Tests demonstrated that the induced charge flowing from ground to the antenna through a resistor generated a signal that was suitable for firing the spark. Signals from antennas at each of the spark photography stations triggered the discharge as the projectile passed through the field of view.

There remained the problem of generating a pulse from the discharge to operate chronographs that would record the time at which the photograph was taken. Early designs of spark gaps gave an unacceptable dispersion between the timing signal and the photograph. Dr. A. Hull, a member of the BRL's Scientific Advisory Committee, recognized where the source of dispersion lay and recommended a spark gap developed by the General Electric Co. for use in a radar apparatus. Dr. Charters, BRL, together with Dr. L. Tonks, GE, successfully adapted the radar gap to spark photography. Their design permitted the main spark to be fired within a microsecond of both the trigger and timing signals.

Once the instrumentation was proven, the Aerodynamics Range was fitted with twenty orthogonal spark shadowgraph stations positioned along its 300-foot length. Timing data on spark firing were recorded on a drum chronograph and, subsequently, on electronic counters. Accurate interpretation of the massive amounts of data produced by the Range required a considerable amount of analytical work. From a set of forty photographs, two per station, the spatial location and orientation of the projectile had to be computed. To insure accuracy in these calculations, the Range had to be precisely surveyed. A procedure was evolved using techniques established by the U. S. Coast and Geodetic Survey. The components of the spark shadowgraph stations were aligned to the required accuracy of 0.001 foot. Dr. E. J. McShane of the University of Virginia, along with BRL mathematicians and scientists, developed methods of analysis for determining the properties of projectile flight from the spark photography and chronograph records.

When put into use in 1943, the BRL Aerodynamics Range made possible, for the first time, the recording of accurate histories not only of projectile motion, but also of the detailed, transient flow structure about the round. Although the size of the range limited its use to missiles having a maximum diameter of 40mm, there were no limitations placed on the imagination of the operational staff or on the configurations that required testing. By developing pioneering launch techniques, the staff were able to contribute to studies of projectile, missile, and aircraft aerodynamics in all flight regimes from subsonic through hypersonic velocities.

Figure 5. First meeting of the BRL Scientific Advisory Committee, September 1940. Front row, from left: Mr. Kent, Prof. Urey, Prof. Rabi, Dr. Dryden, Dr. Lewis, COL Zornig, Dr. Hull, Prof. von Karman, Prof. von Neumann, Prof. Russell, Dr. Dederick. Second row, from left: LT Gillon, Mr. Lane, Mr. Reno, Mr. Hitchcock, Dr. Charters, CPT Simon, Dr. Hodge, Mr. Beeman, Mr. Tolch, Mr. Gay, LT Steele. Third row, from left: Mr. Moerman, Mr. Dickinson, Mr. Carr, Mr. McNeilly, Mr. Shanks, Mr. Leeder.

B. Supersonic Aerodynamics

Shadowgraphs of projectiles traveling at supersonic velocities revealed in minute detail the shock wave patterns they created. Since projectiles, bombs, and missiles were the only objects during World War II capable of flight at these velocities, researchers working in the area of ballistics dealt extensively in the infant science of high speed gasdynamics.

In supersonic flight, shock waves develop in the air as the body passes. The "sonic boom" of high-speed aircraft and the "crack" of a bullet are characteristic shock processes. The presence of shock waves in the flow significantly influences drag and stability. Accordingly, study of these waves quickly became a program of major importance.

Early in the war, Drs. Charters and R. N. Thomas of BRL took advantage of the powerful main shock wave of the projectile to carry out experiments on the reflection of such waves from plane surfaces. Heavy, metal plates were placed adjacent to the trajectory. As the projectile passed over the plate, its associated shocks were reflected from the surface. Spark photographs recorded the interaction between incident and reflected waves. The records were used by the personnel of the Manhattan Project to assess the blast from nuclear explosion.

Toward the end of the war, Dr. John von Neumann, of BRL's Scientific Advisory Committee, suggested a wavelet theory on which a procedure for determining total airflow around a high-velocity projectile could be based. It had been noted that exceptionally good spark photographs of high-velocity projectiles in flight showed wavelets originating at different points on the surface behind the shock wave, caused by slight irregularities on the surface and turbulence in the boundary layer. When the shape of each wavelet was carefully examined and the information derived from the complete study put together, it was possible to determine the general characteristics of the flow.

In his classic paper, "Some Ballistic Contributions to Aerodynamics," Dr. Charters presented results of wartime research to the Institute of Aeronautical Sciences meeting in New York during January 1946. This work provided experimental data to validate the aerodynamic theories of Drs. Theodore von Karman and G. I. Taylor. His investigations into the drag of slender, axisymmetric bodies had direct application to both projectiles and aircraft. It is interesting to note that the first aircraft to attain supersonic flight, the Bell X-1 rocket plane, had a fuselage design configured after a 0.50-caliber projectile shape.

C. Transonic Aerodynamics

With projectiles flying at speeds near the velocity of sound, experimental results indicated the existence of strong destabilizing aerodynamic forces and moments. Since existing wind tunnels exhibited the influence of wall interference at transonic speeds, the BRL Aerodynamics Range was employed to develop the stability characteristics of missiles in this flight regime.

The flow in the vicinity of the projectile base was determined to be particularly critical. Since boattails were commonly employed to reduce aerodynamic drag, transonic flight dynamics of such designs was of practical interest. Test firings quickly uncovered potential difficulties with certain boattail configurations. The results of these early studies made possible the correction of problem areas and still form a baseline for modern projectile design.

Bombs dropped from high altitude also had transonic problems . As they accelerated, the bombs passed through transonic velocities, which introduced flight instabilities that degraded accuracy and proper fuze functioning. Many bomb models were fired in the Aerodynamics Range to uncover and correct potential difficulties. Among the more important models were the early atomic bomb shapes.

D. Service Support

To give maximum assistance to weapons and ammunition designers, the exterior ballisticians at BRL devoted a considerable part of their time to service work. Models of new shell, rockets, guided missiles, and bombs were tested in the free flight range to provide design data. In addition, a large amount of troubleshooting was done to determine, for example, what caused a new shell to be unstable in flight or a new rocket to be inaccurate.

The munition developments of World War II were considerable. Fin-stabilized, kinetic energy projectiles were introduced by Germany late in the war. These projectiles were found to be inaccurate if they possessed aerodynamic or inertial asymmetries. Tests at BRL demonstrated that the effect of these asymmetries could be reduced, with an associated accuracy improvement, if an initial spin or roll was imparted to the round. However, it was also discovered that the permissible spin rate had definite limits. If it were too fast, a side force developed, leading to instability. If it were too slow, resonance between roll and yawing motion could result, leading to "catastrophic" growth in the yaw angle. These concepts form a basis of design for all modern fin-stabilized rounds.

A fundamental contribution to the development of high-explosive, shaped-charge projectiles was made almost accidentally. During experiments to measure the drag on sharp- and blunt-nosed projectiles, it was found that the addition of a spike, protruding from the nose of a blunt projectile, reduced the drag to a value near that of the streamlined design without the associated loss of stability. This result formed the basis for the design of the fin-stabilized, spike-nosed projectiles currently used with shaped-charge warheads.

When high-speed aircraft were introduced during and following WW II, they imposed conditions of fire so different that it was necessary to provide completely new techniques for predicting flight characteristics of projectiles fired from aircraft guns. In this case, the speed of the aircraft was a major factor affecting both the velocity and the yaw of projectiles. Heretofore, when the effects of aircraft speed were much less pronounced, the ballistics could be determined experimentally by ground firings. With modern aircraft, these data did not transfer to flight tests. Subsequently, Aerodynamics Range tests to measure the dynamic stability characteristics of rounds fired under the realistic conditions readily demonstrated that fire control solutions were incorrect. Based on validated aerodynamics, new solutions were computed that permitted accurate fire.

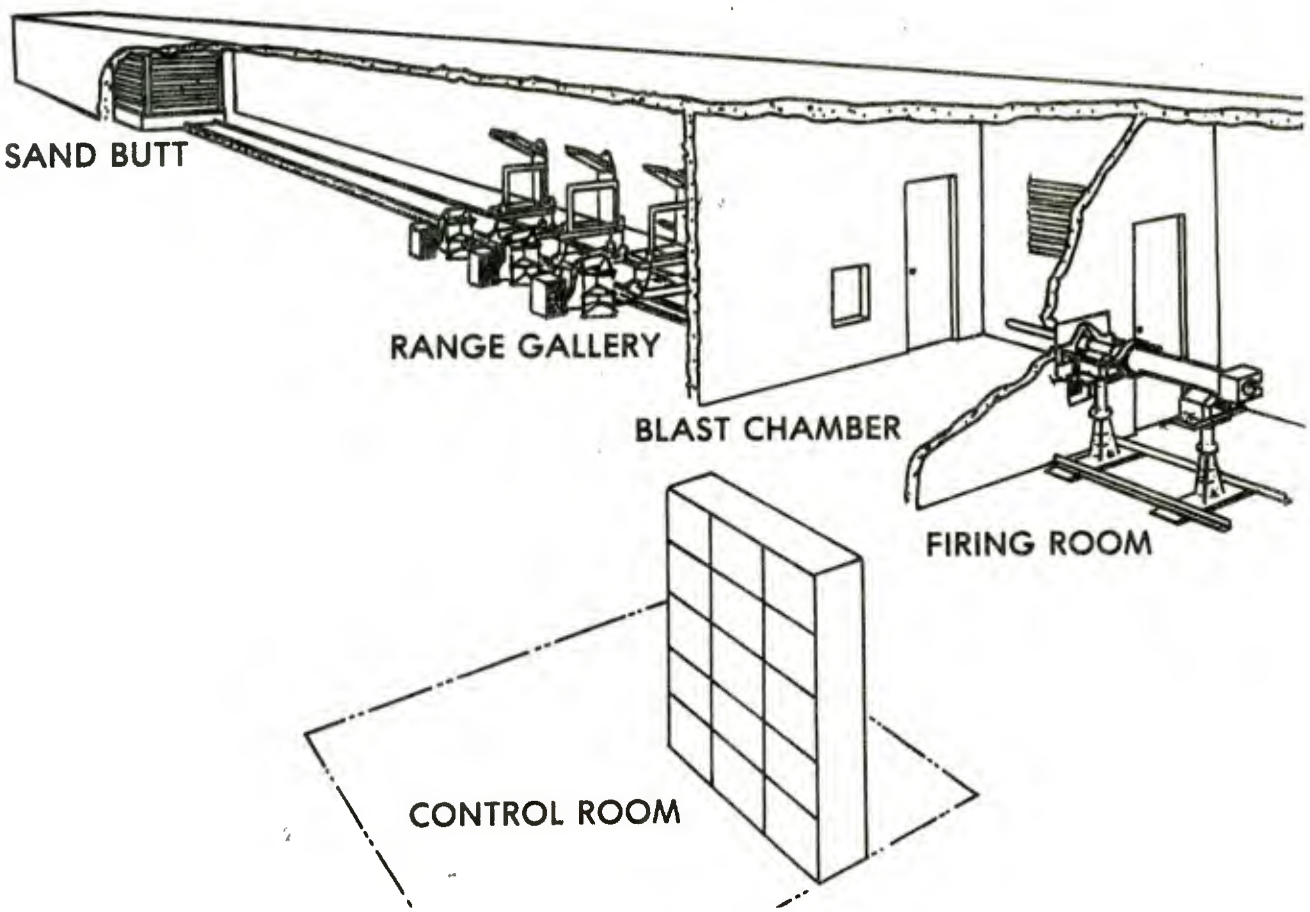


Figure 6. Schematic of the Aerodynamics Range

E. Mechanical Specifications

The Aerodynamics Range is an enclosed facility instrumented to launch a missile in free flight and record its motion over a 285-foot trajectory. The technique for obtaining the aerodynamic coefficients demands unusual accuracy in the measurement of time, distance, and angle. The required accuracy in distance and angle was developed using spark photography. This recording procedure gives distance accuracy to 0.001 foot and angular accuracy to two minutes of arc. The roll angle can be determined to an accuracy of less than one degree. Time interval measurements are obtained to an accuracy of 0.1 microsecond.

The range area consists of the firing room containing the launcher, the blast chamber isolating the instrument area from the muzzle blast, the range gallery containing the apparatus for recording the flight of the missile, and the control room from which operations and data recording are conducted. Additional facilities and activities necessary to obtain ballistic data are the model shops, the physical measurements section, the data reduction section, and the program engineering section.

To obtain aerodynamic coefficients over a range of Mach numbers, firings must be conducted at several velocities. Since the loss in velocity generally is small over the 285-foot trajectory, the aerodynamic coefficients can be assumed to be constant and each round gives data at only one velocity, that at mid-range. For complete information on the missiles' characteristics, rounds usually are fired at a minimum of seven different velocities: three supersonic, two transonic, and two subsonic.

There are practical limits to the size, weight, and velocity that can satisfactorily be tested in the Aerodynamics Range. The minimum size, a 1/8-inch sphere, is determined by the sensitivity of the apparatus. The minimum velocity, 600 feet per second, is determined by the shape of the parabolic trajectory due to gravity. The maximum size missile, a 1.5-inch body diameter, is determined by the ability of the blast chamber to withstand the muzzle blast.

The missile is launched from a gun mounted in the firing room with the muzzle in the blast chamber. The gun is positioned so that the trajectory traverses the field of the spark photography stations. The function of the stations is to provide position data on the missile at 45 points along the 285 feet of the trajectory. This is achieved by a photographic technique. The station is essentially a specialized camera. To the right and below the trajectory the station supports two photographic plates. To the left of the trajectory is the point light source generated by a short duration spark gap. Above the trajectory a mirror is supported by the station frame.

When the round is fired, the enclosed range gallery is dark. As the missile approaches each station, it breaks a light beam, thereby triggering the spark light source. The diverging rays of light from the spark silhouette the image of the missile, its shock waves, and the fiducial marks of the station on the two photographic plates. Both plates are exposed from the same light source: the vertical plate directly and the horizontal plate from the light reflected by the mirror above the station.

For the analysis of the range data, it is necessary to know the velocity of sound and the density of the air in the range at the time the round is fired. The range is air-conditioned to keep these factors reasonably constant. Immediately after each round is fired the temperature is measured at three stations in the range, the air pressure is obtained from a standard mercury barometer, and the relative humidity is observed.

The limitations on model scale imposed by the size of the facility resulted in the development of the BRL Transonic Range in 1946. The technical capabilities of the Range inspired a significant effort to construct similar facilities. The pressurized range constructed at the Naval Ordnance Laboratory, White Oak, Maryland, can be traced directly to the BRL Aerodynamics Range. Ranges at Eglin Air Force Base, Florida; Arnold Engineering Development Center, Tennessee; NASA-Ames Research Center; and even Meppen Proving Ground, Germany, can be related to early developments at BRL. The Range has served the nation in peace and in war. Today, it continues this tradition as a unique facility for producing high quality data in the field of ballistics.

IV. KEYNOTE ADDRESS

"EARLY HISTORY OF THE AERODYNAMICS RANGE"

By Alexander C. Charters

Thank you for inviting me to give the Keynote Speech at the ceremony designating the Aerodynamics Range as a National Mechanical Engineering Landmark. It is an honor to participate in your ceremony and a pleasure to tell you about the early history of the Aerodynamics Range. I invested a significant part of my life in getting the Range going, and I'm delighted to see it turn out so well.

The development of the Range started in 1940. By 1944 the Range was operating and by 1946 the Range was instrumented essentially as you see it today. There have been many improvements since then, but the basic technology and mode of operation had been laid down nearly forty years ago. Now, forty years of continuous operation without major changes is unique for a facility whose primary components are electronic. Out in Silicon Valley on the West Coast, instruments go from one generation to the next in three years. At three years a generation, the Aerodynamics Range is now more than ten generations old. A human generation is fifty years or more, and, in terms of human history, ten generations would give the Range an age of 500 years, placing its start back in the 15th century when knighthood was in flower. The Range still operates, but there are very few knights in armor galloping about the countryside.

I'll begin the early history with a question: "What is an Aerodynamics Range?" An Aerodynamics Range is an enclosure instrumented to record the flight of a projectile. A launcher propels the projectile into the enclosure. The instruments record its flight as the projectile passes through.

The enclosure, the launcher, the projectile, and the instruments depend on what you want to find out. Ranges have been used to study all sorts of things. I understand that once upon a time the Transonic Range, the big brother of the Aerodynamics Range here at APG, was turned into a baseball diamond to solve the mysteries of that famous pitch, the knuckleball. Other ranges have been used to study the re-entry of ballistic missiles into the earth's atmosphere and the impact of meteoroids on the moon's surface. BRL's Aerodynamics Range was developed to measure the drag and stability of small-arms bullets and artillery projectiles. But the path to its goal had a few twists and turns. The war had started and the range was first put to use in impact tests of aircraft armor. Then we measured the drag of shell fragments; a very messy set of firings. Then came a very rewarding program. We measured the drag of spheres from subsonic, through transonic, to high supersonic velocities--a first for this measurement. We were proud of our results and showed them to some of our friends at BRL. "Yes," they commented, "Very good! Now you're ready to fight the Civil War."

In 1940, the military situation set the need for the Range. At this time, the Gun was a primary weapon of the battlefield. Guided missiles had not yet been invented.

The soldier expects the projectile fired from his gun to do two things: (1) hit the target, (2) hit the target pointed head-on. In its flight from gun to target, the projectile encounters large aerodynamic forces which retard the projectile, the drag, and will tumble the projectile end over end unless it is stabilized by spin, gyroscopic stability, or with fins, aerodynamic stability.

Give the ballistician the drag and stability of a projectile and the muzzle velocity and aim of the gun, and he can compute the trajectory, the time of flight, and the oscillating motion associated with its stability. You could call this computation the "direct ballistic problem." On the other hand, give the ballistician records of the projectile's position, its time of flight, and its orientation along the trajectory, and he can determine its drag and stability. You could call this computation the "indirect ballistic problem." The Aerodynamics Range functions by solving the indirect ballistic problem.

The problem we faced in 1940 was how to measure the position and orientation of the projectile. The measurements could have been made from photographs of the projectile in flight because photography was accurate and didn't interfere with the flight. But the projectile moved at high speed, traveling several feet every thousandth of a second, and rapidity of its motion caused problems with the photography.

You might think that stopping the motion was the main problem, but this was not the case. In fact, a method of photography had been developed in the 1880's that "stopped" the motion and gave excellent pictures of projectiles in flight. The method was called "spark photography."

A capacitor discharged through a small gap generates a spark that is quick, bright, and small. It lasts only a few microseconds, short enough to stop the motion. It is virtually a point source of light, so the photography is greatly simplified. The spark photograph is taken in a dark range. A photographic plate is placed on one side of the trajectory, the spark gap on the other side, and the spark is fired when the projectile is in front of the plate. The spark exposes the entire plate except for the silhouette cast by the projectile. The silhouette is a sharply defined projection of the projectile and is excellent for measurement of position and orientation.

If spark photography were available in the 1880's, why did it take more than 50 years to be used in an Aerodynamics Range? The problem lay in triggering the spark when the projectile was in front of the plate. Ernst Mach took excellent spark photos of projectiles in flight in the 1880's, but he took them so close to the gun muzzle that he could use the muzzle blast to trigger the spark. He could not take spark photos very far from the gun.

In the late 1930's here at the BRL, Robert Kent tried to use spark photography to photograph projectiles in flight. He triggered the spark from the recoil of the gun, but this method of triggering did not work. Kent's efforts to develop a spark photography range were not successful. However, his experience was useful; it suggested that the projectile itself must trigger the spark.

When I arrived at the BRL in 1940 having completed a post-doctoral year at Cal Tech, COL Zornig, Director of the BRL at that time, assigned me the task of designing and building the Aerodynamics Range, starting with the development of a spark photography station triggered by the projectile. My assignment marked the beginning of the Aerodynamics Range.

The first step was to develop a method for triggering the spark from the projectile. To make a long story short, I chose to investigate the potential of an electrostatic antenna. Tests elsewhere indicated that the projectile was charged electrically and would generate a signal on an antenna placed close to the trajectory. The scheme worked. The projectile was charged, and the signal from the antenna switched on a mercury trigger tube and fired the spark. The mercury tube was made especially for our use by Harold Edgerton.

I remember my first spark photograph. I picked up the negative and rushed over to COL Zornig's office to give him the good news and ask for permission to build the Aerodynamics Range. I can still remember his reply: "Alex," he said, "this is excitement. Your experiments are going well. But remember Mach could take a spark photograph, just as you have, over 50 years ago. Lots of people have taken just one photograph of a projectile in flight. The real accomplishment will be taking a series of spark photographs one after the other along the trajectory. Now, go back to your Range and build three spark stations. When you've succeeded in taking three photographs one after the other of the same bullet, come back and I'll give you permission to build the Range."

First, I had to solve the problem of recording signals from the Range. We were recording on the drum chronograph, an advanced instrument for its day, but a fussy one to operate. One had to stand over it, twiddling dials until everything was running just right before taking the record. The drum chronograph was situated on the first floor of the Instrument building (now long gone); the range was located in the basement. I had to operate the chronograph and fire the gun myself, since I was working alone at this time; so I had to fire the gun remotely from the chronograph room.

Today, you'd simply buy a solenoid to pull the trigger. But we didn't have a solenoid and it would have taken a long time to purchase one. We had to rely on our own resources. I made a crude solenoid from a roll of wire and an iron rod, but it was so weak that it couldn't pull the trigger of the gun. I then rigged up a weight sliding on a rod. The weight was attached to the lanyard, and its fall would pull the trigger. But my solenoid was too weak to pull the catch that released the weight.

Then I had an idea. I called my friend, Bill Dickinson, in the Ad Building and asked: "Bill, do you have any mousetraps?"

"Why, yes," he said, "We've had some trouble with mice. Do you have them in the Range, too?"

"No," I said, "I need one for an experiment. I'll tell you about it later; just send me over a couple."

So Bill sent me a mousetrap and it did the trick!

This is the way it worked. I was in the chronograph room fiddling with the drum chronograph. When it was running okay, I closed a switch sending a current through my solenoid, retracting its iron rod, and tripping the mousetrap; the bail of the trap pulled the catch, releasing the weight; the weight fell, jerking the lanyard, pulling the trigger and firing the gun.

A couple of days later Bill came over to see what I'd done with his mousetrap. I showed him the apparatus and how it worked. I forget his exact comments, but distinctly recall that he stuffed me into the category of the "Mad Scientist." From then on a stream of visitors showed up at the Range. They'd come in, take a look at the apparatus, and laugh. They didn't even say, "Hello."

I finished the second station, but never got to the third. The war was about to start, and Bob Kent directed me to use the Range with its two spark stations for a test of a new kind of aircraft armor. When the armor test was through, the main BRL building and the present Aerodynamics Range enclosure were finished, and it was time to move in.

There's a story about the enclosure of the Aerodynnamics Range that has always intrigued me. When COL Zornig was planning the BRL building and Range, he asked Kent: "Bob, what is the greatest length you'll ever need for the Aerodynamics Range?"

After some thought, Kent replied, "100 feet."

Zornig then tripled Kent's estimate and specified a length of 300 feet. Experience has shown that Zornig's length of 300 feet is just barely enough.

The aircraft armor test didn't really delay the development of the Aerodynamics Range because it vindicated the use of an electrostatic trigger for our spark stations. I was given authorization to build six spark stations for the new Range. By then Betty Richards, and later Walter Braun, and still later Dick Thomas and others joined me to help out. The six new stations were evenly spaced along the first 50 feet of the range. They were wooden structures, but the spark gaps and photographic plates could be positioned with reasonable accuracy.

Then disaster struck from two directions. First, we couldn't get any more of Edgerton's mercury tubes for triggering our sparks. His glass blower was all tied up on a high priority project. Edgerton suggested that we try a 3-electrode gap. Make the main gap wide enough to hold off the 6,000 volts; fire a trigger spark to ionize the air and fire the main spark. We built a 3-electrode gap, and it worked fine. Or so we thought at the time.

Then our order for photographic film bounced. We were in the war by this time; the Air Force was in charge of the distribution of all photographic film; we didn't have a high enough priority. One of the astronomers at the BRL--I forget who--suggested that we try photographic plates. Photographic plates are the same as film except that the emulsion is laid down on a glass instead of a plastic film. Perhaps the Air Force had never heard of plates, and anyway, plates might be better for our use.

Sure enough! The Air Force hadn't heard of photographic plates. Our order went through and subsequent experience verified the superiority of plates over film. We did have a small problem with the Receiving Section at BRL. A clerk opened the box containing the plates and counted them; then she put them back and sent the box on to us. Of course, the plates had been exposed and were useless. In due course, we convinced the Receiving Section to trust the manufacturer and send our plates on to us unopened.

Finally, the great day came. The six stations were finished, and the Range was ready for test. After the usual shakedown firings, we were rewarded with six sets of beautiful spark photographs. We were elated! But not for long. Disaster struck again! The timing record didn't make any sense. The times of flight were about right, but when we computed velocities from successive time intervals we couldn't make heads or tails of the data. Something was seriously wrong. But what? No one at BRL knew the answer.

We brought the problem up at the next meeting of BRL's Scientific Advisory Committee. After listening to our tale of woe, Dr. Albert Hull from the General Electric Company pointed out the problem was a delay of several microseconds between the trigger spark and the main spark. The trigger spark was recorded by the chronograph, but the light for the photos came from the main spark, so the picture and the timing signal were not synchronized. The delay was not long enough to lose the picture but plenty long enough to mess up the timing record.

The delay was caused by the design of the 3-electrode gap. G.E. had had the same problem with a spark gap for a radar apparatus and had learned how to design a spark gap that fired trigger and main sparks simultaneously. Walter Braun and I went to the GE Lab in Schenectady and spent a month there working with Lewi Tonks, who had developed GE's radar spark gap. We were successful in adapting GE's radar gap for our use. Our new gap was a total design change, and main trigger sparks now fired synchronously. The Schenectady trip was a rewarding experience.

We returned to the BRL, built six new gaps, and installed them in the spark stations. Everything worked fine. The timing signals finally made sense and we were rewarded with excellent drag measurements, as the sphere firings demonstrated. We were now ready to build the full complement of spark stations and put the Range to work at its designated job of determining the drag and stability of small-arms bullets and artillery projectiles.

Well, almost ready. Two more items of technology were needed. First, we had to measure the length of the range accurately. We used only the first 50 feet of the Range for the sphere tests, but we would require the full usable length of 280 feet for tests of long, streamlined projectiles. We divided the length of the Range into four 70-foot intervals and set ourselves the task of measuring a 70-foot interval to 0.001 foot or better, the accuracy required for good drag determinations. Now, you cannot measure a 70-foot length to 0.001 foot with an ordinary steel surveyor's tape; something better is required. I visited the Coast and Goedetic Survey in Washington and asked them how to do it. They replied that they used invar tapes, suspended with a constant tension. They offered to send us one of their invar tapes, and of course, we were delighted to accept.

We supported the tape at each end, leaving it freely suspended over the 70-foot interval, and pulled it with a weight for constant tension. I remember when the invar tape arrived. It was a most uninteresting strip of metal. There were no markings at all except for two tiny punch marks with a scratch in between at each end. When we suspended the tape, it twisted 90 degrees in the center. I was afraid they had sent us an inferior tape and called them to ask about the twist in the center. "Oh," they replied, "you have one of our best tapes. Most of them twist 180 degrees in the center."

The survey system worked beautifully. No disasters this time. We measured the 70-foot intervals repeatedly to an accuracy of 0.001 foot, nearly one part in 100,000. I think we really measured with an accuracy of one part in a million. We could measure the change in the length of the Range from summer to winter.

The final item of technology was the cycle counter chronograph. The drum chronograph had served us well, but its limit of 4- to 5-microsecond accuracy was not quite good enough. In fact, the advent of the cycle counter made all other chronographs obsolete. In 1944 the operating rate for cycle counters counting in the decimal system was 100,000 per second--slow by modern standards. Unfortunately, transistors and integrated circuits lay far in the future. However, we were able to design a cycle counter that operated at a rate of 1.6 million counts per second. Our cycle counter chronographs measured times with an accuracy better than a microsecond.

We built 25 permanent spark stations with steel frameworks which were adjustable so that the plates and reference marks could be positioned as required and aligned accurately. We devised various instruments for alignment and survey purposes. We built special racks for handling and developing the 11- by 14-inch photographic plates. The range itself was finally ready for carrying out its original mission, determining the drag and stability of projectiles.

But there were other things needed before we could carry out our assigned task. The properties of the projectiles themselves had to be measured: properties such as dimensions, centers of gravity, and moments of inertia. Then there was the problem of reducing the measurements of position, time, and orientation to determine the drag and stability. BRL scientists, assisted by Dr. E. J. McShane of the University of Virginia, devised procedures for computing the theoretical parameters of the projectile's motion to give a "best fit" to the experimental data. Once the parameters of the motion were known and the properties of the projectile were measured, determination of drag and stability was straightforward.

A "computer" in the early 40's consisted of a girl punching numbers into a mechanical calculator. Our "computer girl" took about a day to reduce the records from one shot. Modern computers could make the reduction in a matter of seconds. But I'm old-fashioned; I still prefer the girl to the machine.

The history of the range is more than a story of its technology. The people who developed and operated the range all played vital roles. I particularly remember the girls who made up most of our complement. After the war started, all the men went into the Armed Services and there were none available for technicians and engineers, except for a couple of "rare birds" like Walter Braun and myself. We either built and ran the range with girls, or not at all. We bowed to the inevitable, hired the girls, and put them to work.

Then we made a marvelous discovery. The girls could do everything the men could do! Betty Richards ran the measurement lab, wrestled the gear around in the range, and even badgered Ted Stern when he refused to remove a huge box of 20mm projectiles he had left right in the middle of her lab. Lois Lonberger was my Range Chief. She loaded and fired the guns, operated all the instruments, and even trapped Walter Braun one day when I wasn't looking. We had some heavy 40 pound lead weights for holding down some frameworks in the range. I remember standing in the door one day watching Lois and Betty walking down the range corridor with a 40 pound weight in each hand, their feet sinking gently into the concrete at each step. And I thought, "Men, the glory's gone; the girls are in the act for good."

We were a happy group. During the war we worked a 10-hour day. Now, 10 hours is a long stretch, and to squeeze a little more out of the human frame at the end of the day we took a break from 4:00 - 4:30 in the afternoon. We gathered in the measurements lab; the girls made tea and served cookies they had brought from home. Our half-hour tea break did wonders. We got to know one another and morale was high. We were refreshed and then could work on pretty much at full speed until quitting time at 7:00, or later, in the evening.

Our friendship extended beyond our work area at the BRL. Len MacAllister and I liked to go fishing on Romney Creek. One afternoon we arrived at a favorite pool, baited our hooks, cast our lines out in the water, set our poles against forked sticks, and sat down to wait. Len pulled one of his gigantic pipes from his pocket, stuffed in a bushel basket of tobacco, lit up, tamped the tobacco down, and puffed away contentedly. And a good thing, too. There's nothing like the smoke from Blue Boar pipe tobacco to keep the bugs away. We were chatting about this and that when I heard a strange buzzing noise. Must be some kind of a new insect, I thought. Len didn't say anything. The buzzing grew louder and louder. Finally, I asked Len: "What do you suppose that buzzing is?" Len leisurely took a couple of puffs. Then he took his pipe out of his mouth, turned slowly in the direction of my fishing pole, and said, "Well, I think it's your reel." And so it was. The click on my reel was buzzing. An enormous catfish had taken the bait and was hauling my line gently down to the Chesapeake Bay.

Somehow it seems to me that the Aerodynamics Range has suffered the same fate. People have grabbed on to the concept of the range and hauled it to other places for other uses. The movement started with our building the Transonic Range here at the Aberdeen Proving Ground. Then the ranges at the Naval Ordnance Laboratory came next, if I'm not mistaken. But all these subsequent developments, fascinating as they are, are "a story for another day," as it were. The early days of the Aerodynamics Range are long behind us, but it's been fun telling you about them. And, I hope, a rewarding experience as well, because the philosopher, George Santayana, tells us that "Those who cannot remember the past are condemned to repeat it."

Acknowledgment

The Director and staff of BRL would like to express their appreciation to the American Society of Mechanical Engineers for bestowing this distinguished award upon the Aerodynamics Range.

APPENDIX

In honor of the occasion, the Governor of the State of Maryland sent a personal representative. Mrs. Constance Beims presented a Governor's Citation to BRL commemorating the event. Dr. Charters received the citation and passed it along the "chain of command" to Dr. C. H. Murphy, Chief of the Launch and Flight Division, BRL. The citation reads,

"Governor of the State of Maryland, to
Aerodynamics Range of the United States Army
Ballistic Research Laboratory at Aberdeen Proving Ground, Greeting:

Be It Known: That on behalf of the citizens of this State, in recognition of your designation as a National Historic Mechanical Engineering Landmark by the American Society of Mechanical Engineers; and as an expression of our best wishes and great respect, we are pleased to confer upon you this

GOVERNOR'S CITATION

Given under my hand and the great seal of the State of Maryland this 21st day of October. In the year of our Lord, One Thousand Nine Hundred and Eighty Two.
Signed: Harry Hughes, Governor and Patricia G. Holtz, Secretary of State."

Figure 7. Dr. Charters receives the Governor's Citation from Mrs. C. Beims

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